Idaho National Laboratory

Milestone Completion Report

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Milestone Title:	Define feedstock baseline scenario and assumptions for the $80/DT target based on INL design report and feedstock logistics projects
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EXECUTIVE SUMMARY

In FY12, the conventional biomass supply system design was completed by implementing field and PDU-scale data from harvest, collection, storage, preprocessing, handling, and transportation operations into INL's Biomass Logistics Model (BLM) and showing an achieved overall supply system cost of $35 per dry matter ton (DMT) or less in 2007 dollars for dry corn stover. This previous work was focused on a niche crop in a high yield area. These types of supply systems were proven to be able to achieve the cost targets for small volumes of material moving through the system. However, these conventional supply systems (CSS) by design do not have the ability to actively manage the feedstock characteristics such as moisture and ash content as influenced by the local climate and supply chain management practices. Because of this conversion facilities are required to handle the operational impacts from biomass variability. In response, more robust biofuel conversion technologies are being developed, even though it is unlikely a single best conversion technology will be capable of handling the variability experienced within raw biomass feedstocks. DOE has identified eight biofuel conversion pathways that the Bioenergy Technologies Office (BETO) is currently supporting R&D toward. This report develops baseline feedstock pathways to support the conversion pathways using cellulosic sugars and bio-oil via fast pyrolysis that can deliver on-spec feedstocks at the conversion reactor throat for less than $80/dry metric ton (reported in $2011).

DOE has established a strategic goal of demonstrating \$3/gge drop-in hydrocarbon biofuel production in 2017. A critical component of achieving that goal is developing supply chains that can deliver high quality, low cost biomass to the biofuel conversion reactor throat. Based on current R&D projections for the conversion technologies a reactor throat feedstock cost of \$80/dry metric ton (reported in \$2011) has been identified as the maximum allowable cost for the feedstock supply chain to achieve the \$3/gge target. There are a range of low cost and niche biomass materials which can be used to achieve the \$80/DMT target. The challenge is that low cost biomass will typically not achieve the specifications required for the conversion processes. This report develops two biomass supply chains that utilize advanced preprocessing strategies to achieve the \$80/DMT reactor throat feedstock cost target while consistently achieving the targeted feedstock specifications. One of the supply chain designs delivers biomass for production of cellulosic sugars and upgrading to drop-in hydrocarbon biofuels. The other supply chain design delivers biomass for fast pyrolysis to bio-oil with upgrading to drop-in hydrocarbon biofuels.

The Feedstock Quality Challenge

A current feedstock supply chain challenge is to reduce the natural variability of the feedstock quality to reduce the impacts to the conversion efficiencies and thus reduce the overall cost of producing biofuel (Figure 1). Additionally, when examining the various characteristics of biomass and comparing the results against the conversion requirements, there is a very limited amount of biomass that meets the in-feed specifications (Figures 2-4). From the feedstock perspective, the questions that arise are can we select, blend or alter somewhere in the logistic supply chain the feedstock so that more of the material will meet the in-feed requirements.

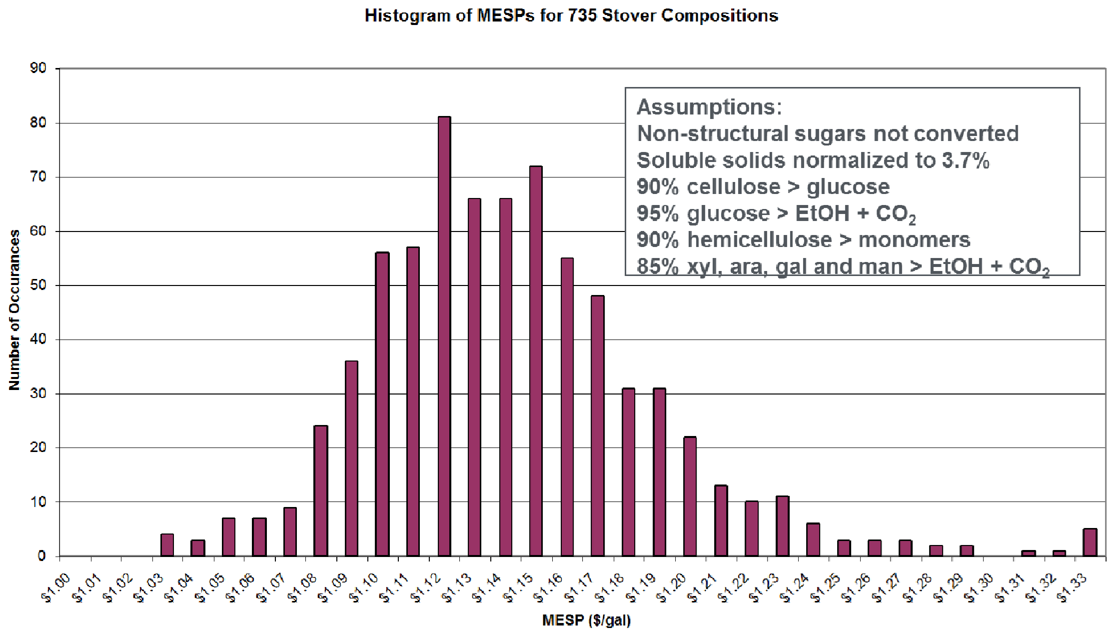

Figure 1: Impacts of variability of sugars to the final MESP price ($/gal).

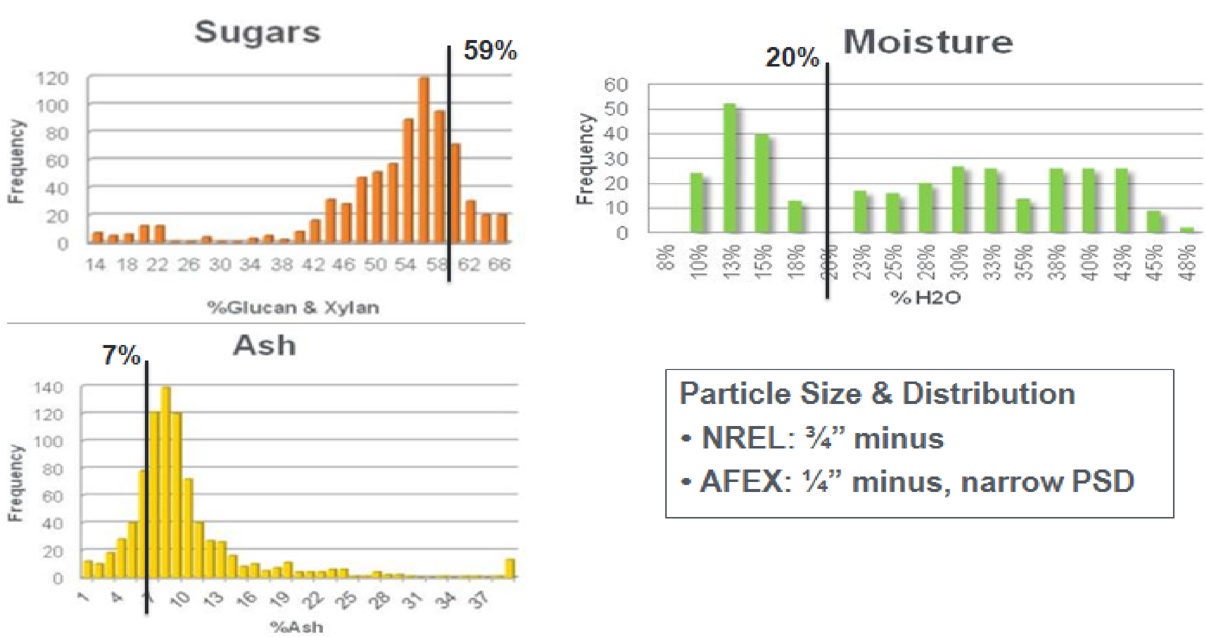

Figure 2: Quality variability versus the design specifications for a biochemical conversion process.

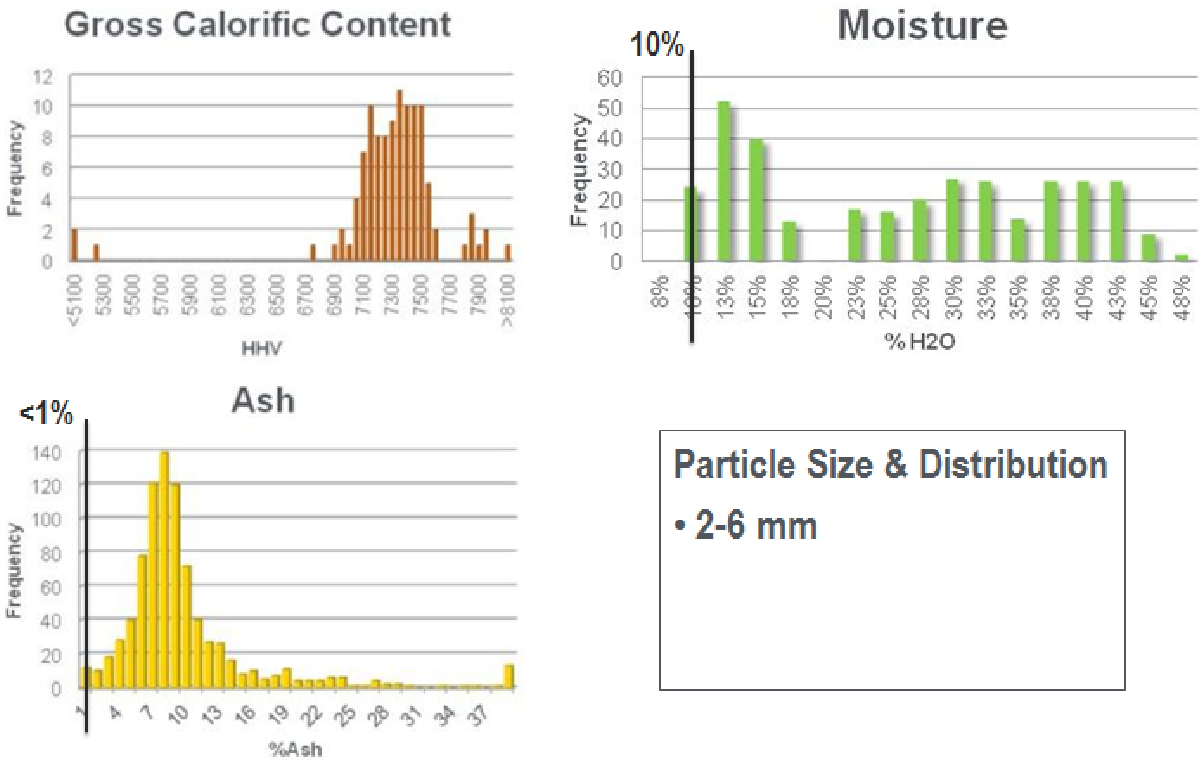

Figure 3: Qualilty variablity versus the in-feed specifications for a thermochemical conversion process.

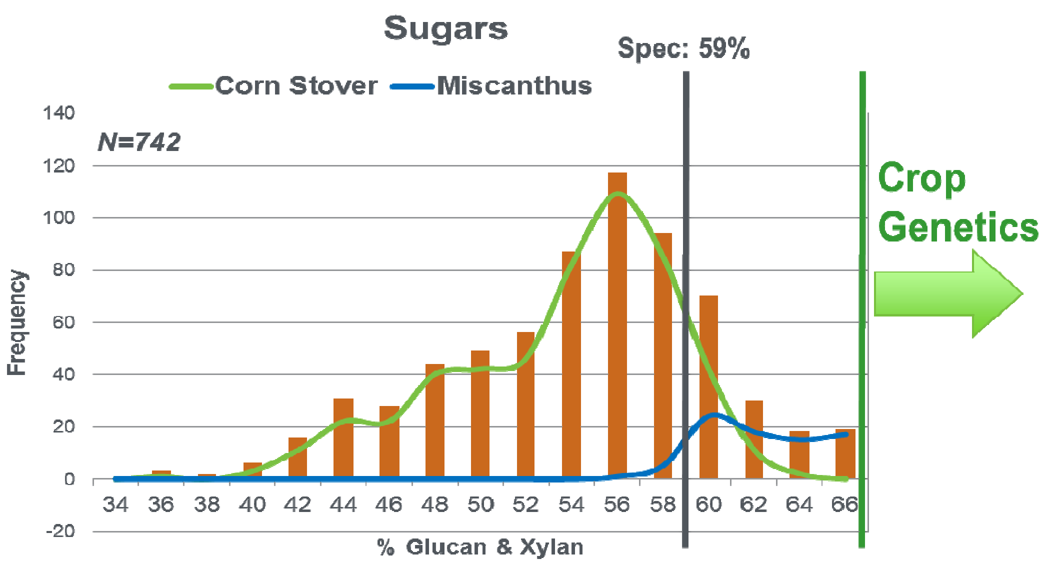

Figure 4: Variability of sugars by crop type compared against the in-feed specification.

The advanced preprocessing concept is to blend multiple feedstocks to get the blended material to meet the in-feed requirements. This will take high quality, high cost material that meets or exceeds the in-feed requirements and blend it with low quality, low cost material. This process does three things: 1) it reduces the overall cost of the material by blending high cost with low cost to come up with a cost in the middle, 2) it reduces variability of the final blended material since we are blending to a certain criteria, 3) it brings more material into the supply system that would not qualify without some type of blending strategy. Figure 7 and 8 outline the concept of blending feedstocks to adjust the blended material to meet the in-feed requirements of the conversion facility.

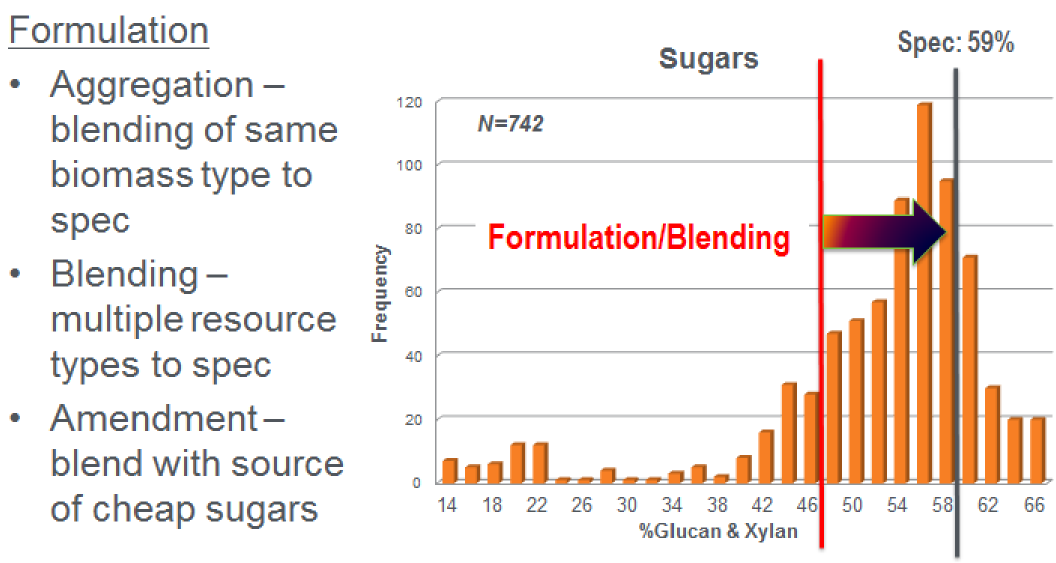

Figure 7: Demonstration of blending multiple feedstocks to achieve the formulation target.

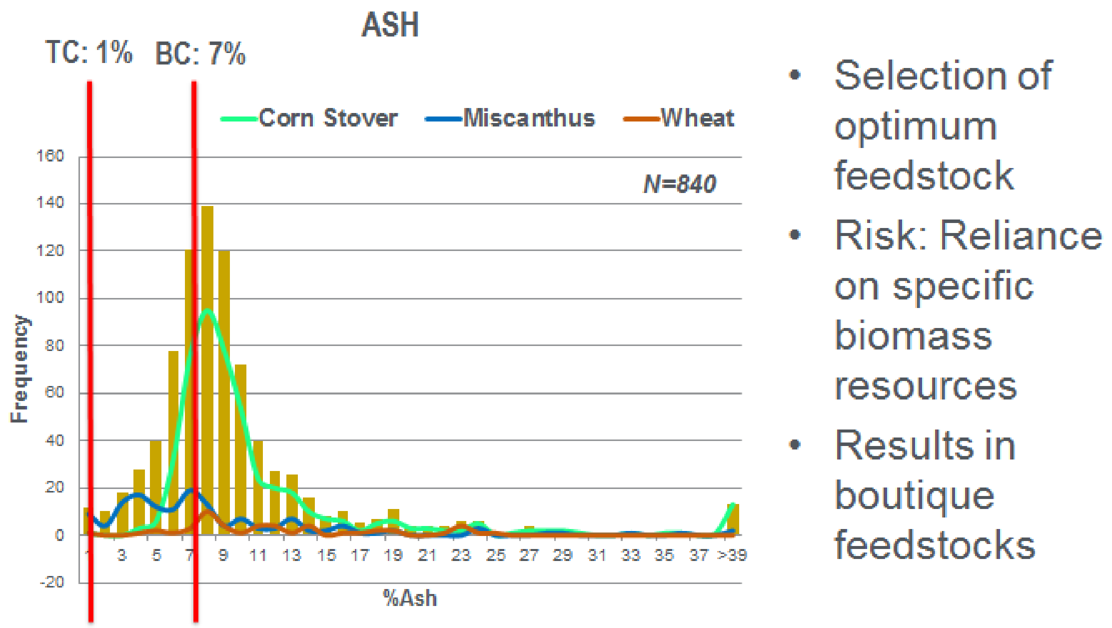

Figure 8: Demonstrates the need to blend corn stover with miscanthus in order to meet the in-feed requirements of the conversion technology.

Finally, we are moving towards a more advanced feedstock supply chain that includes advanced preprocessing unit operations to actively manage biomass quality characteristics. We can design process that clean up the biomass and bring it in-line with the in-feed requirements (Figure 9).

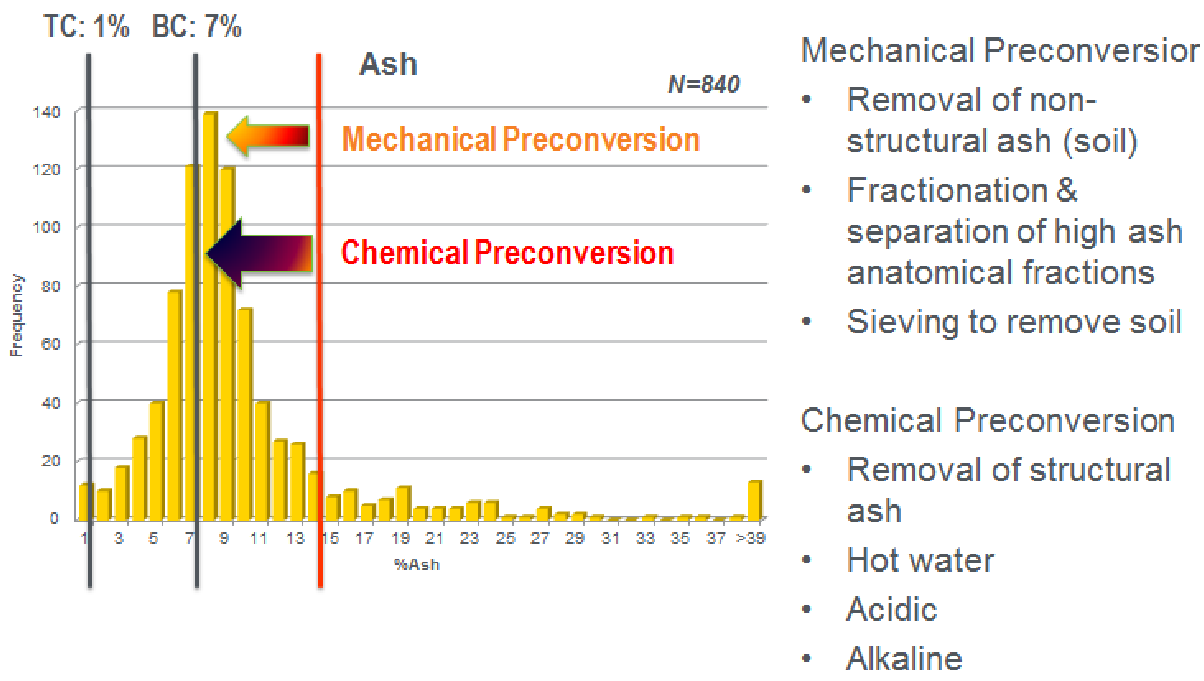

Figure 9: Preconversion then takes us to the final specifiation.

Advanced Preprocessing Designs

The primary advanced preprocessing technology used to achieve the $80/DMT is feedstock formulation. Formulation allows the use of low cost, but typically low quality, biomass blended with higher cost and quality biomass to achieve conversion quality specifications. Formulation also allows the feedstock supply chain business units to adapt to changing market costs and feedstock quality requirements to continue delivering low cost biomass to the conversion reactor throat. Furthermore, the use of low cost biomass allows the supply chain to implement additional preprocessing technologies that actively control feedstock quality.

The first step in developing these baseline scenarios was investigating the regional biomass production supply curves from the US Billion Ton Update to identify “high impact” scenarios to develop and demonstrate the 2017 feedstock supply chain scenarios at the $80/DMT target. Two regional scenarios emerged for the baseline system R&D development and demonstration. The first is a Midwest US scenario delivering a formulated feedstock for cellulosic sugar based conversion pathways. The second is a SE US scenario delivering a formulated feedstock for bio-oil based conversion pathways. It is important to note that the baseline scenarios are regionally focused in order to establish feedstock costs and supply chain technical performance requirements, but the supply chain technologies and designs are broadly applicable across the US.

Cellulosic Sugar Pathway Supply Chains

The basic in-feed biomass quality requirements for the cellulosic sugar to drop-in hydrocarbon biofuel conversion pathways are assumed to be >59% carbohydrate content, <7% ash, <20% moisture and <1/4" particle size. An initial assessment of the low cost, high impact feedstocks from the US Billion Ton Update which can support those specs in 2017 quickly drive to a focus on agricultural residues and perennial grasses, with the primary high impact agricultural residue being corn stover. Figure 1 utilizes the INL Least Cost Formulation Spatial Tool to investigate the farm gate cost profile for corn stover and perennial grasses. There is a wide section of the Great Plains and Midwest US where these materials can be procured at high quantities and low costs. The challenge is consistently achieving the required biomass quality characteristics at the $80/DMT target. Using the Biomass R&D Library the analysis was extended to include biomass quality characteristics for the targeted feedstocks. The formulation strategy that emerged utilizes multi-pass corn stover harvest, single-pass corn stover harvest, and perennial grasses. The key material specifications for each feedstock are shown in Table 1. Multi-pass harvested corn stover is the most abundant and lowest cost resource, but does not meet the primary quality specs of 59% carbohydrate content and less than 7% ash content. Single-pass harvested corn stover is also low cost and has favorable carbohydrate and ash contents, but presents challenges also. Single-pass corn stover does not allow the biomass to field dry. Field drying is typically required to achieve the moisture contents below 20% early in the corn stover harvest window. Later in the harvest window field drying is typically not required and single-pass harvest is viable without requiring biomass drying unit operations in the supply chain. Perennial grasses have desirable feedstock quality characteristics and offer greater biomass per area unit of land than corn stover. The challenge is that perennial grasses will require higher payment to growers and will not achieve the delivered feedstock cost target of $80/DMT. The formulation identified in Table 1 introduces a supply chain that leverages the benefits of each of these feedstocks while mitigating the challenges. It is important to note that implementing formulation advanced preprocessing unit operations is the only way to get dedicated perennial grass feedstocks into supply chains that meet the cost target.

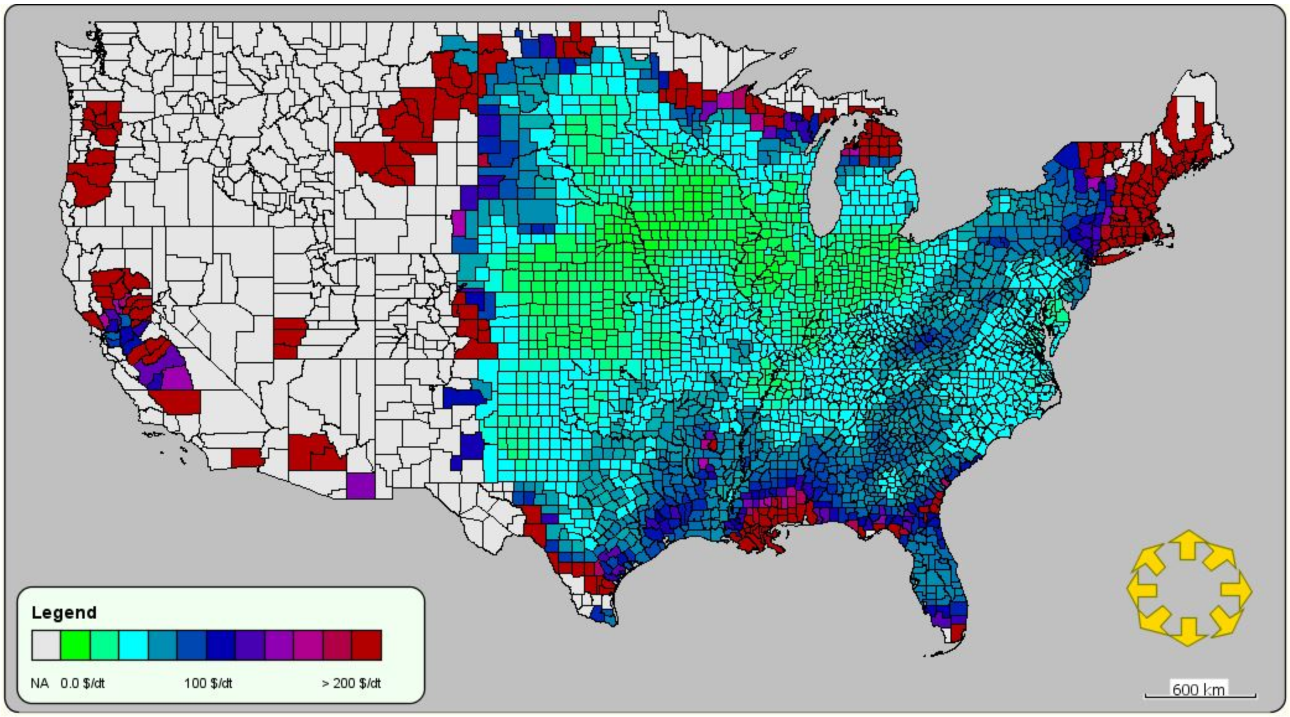

Figure 1. Farm gate cost profile for corn stover and perennial grass blends in 2017.

Table 1: List of costs and specifications for herbaceous feedstocks and blends for cellulosic sugar pathways.

Feedstock	Reactor Throat Feedstock Cost ($/ton)	Formulation Fraction (%)	Carbohydrate Content (%)	Reactor Throat Ash (%)	Reactor Throat Moisture (%)
Multi-Pass Corn Stover	78.24	60	58	9.0	20.0
Single-Pass Corn Stover	78.27	33	60	3.5	20.0
Perennial grass	102.48	7	65	4.0	15.0
Delivered Formulation Totals	**79.94**	**100**	**59**	**6.8**	**19.7**

The supply system design for the cellulosic sugar pathway blends the three feedstocks (corn-stover multi-pass, corn-stover single-pass, and perennial grass) inside the “depot” which is located inside the biorefinery gate. Initial harvest, collection, and field storage occurs on at the farm level while secondary preprocessing, storage, and handling occurs within the gates of the biorefinery (Fig. 2). The individual supply chains for the different feedstocks corn-stover multi-pass, corn-stover single-pass, and perennial grass) are broken out below.

For multi-pass corn-stover harvest and collection includes a combine, rake, baler, and stacking equipment (Fig. 3). Initial storage is carried out at the side of the field in a stack and transportation from the field includes a semi and flat-bed trailer. Within the depot at the biorefinery, storage, and handling and queuing involves an asphalt pad, conveyors, moisture meter, truck scale, dust mitigation, and electro-magnet. Finally, preprocessing involves a grinder. The single-pass corn-stover supply chain is similar to the multi-pass corn-stover supply chain, with the only difference being the harvest mechanism (Fig. 4). The single-pass system uses a combine and pull-behind baler to harvest and bale in one system. Finally, perennial grasses uses a windrower, for the harvest system while the rest of the supply system is the same as the single and multi-pass corn-stover systems (Fig 5).

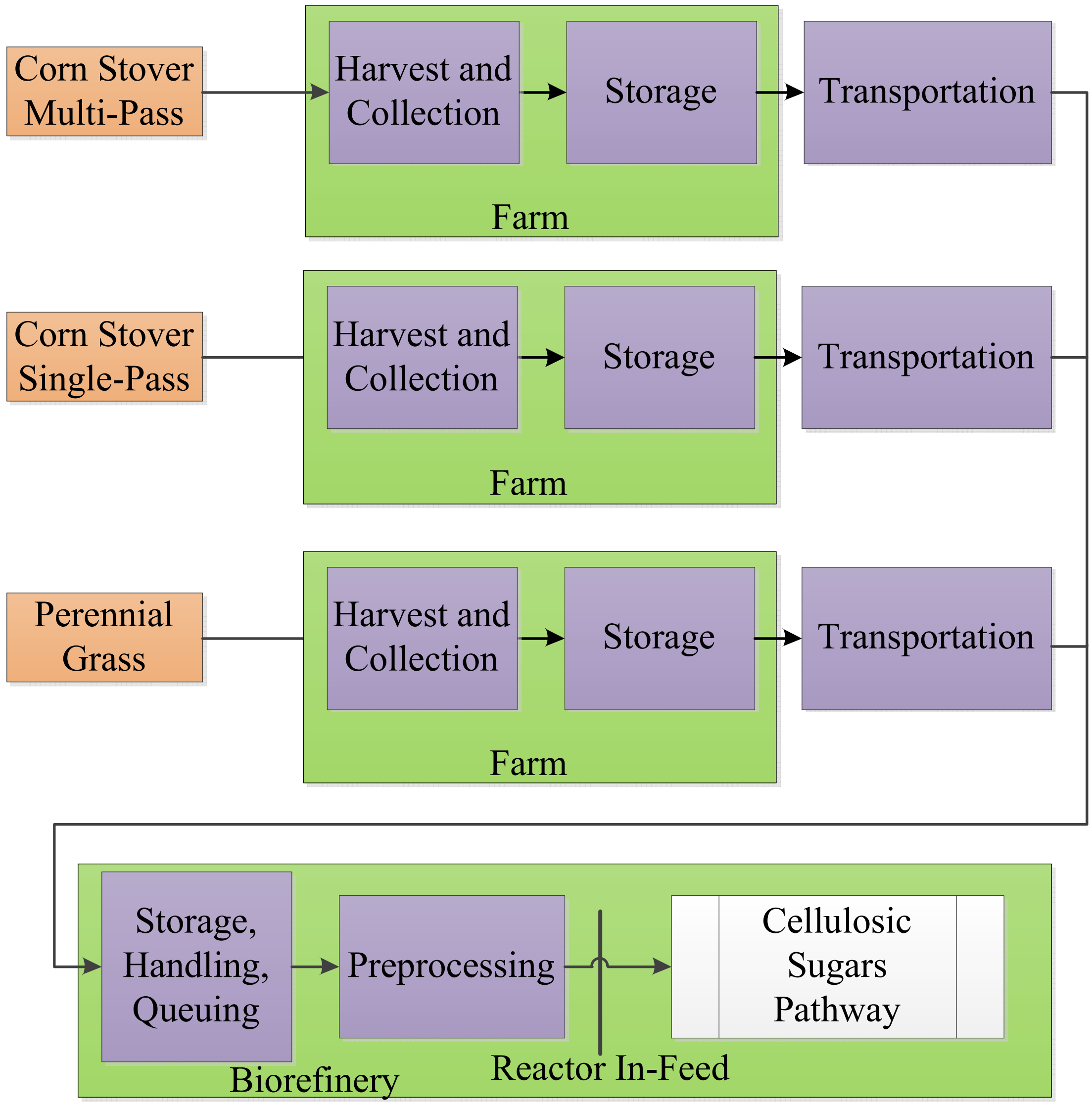

Figure 2. Supply chain design for formulated corn stover and perennial grass.

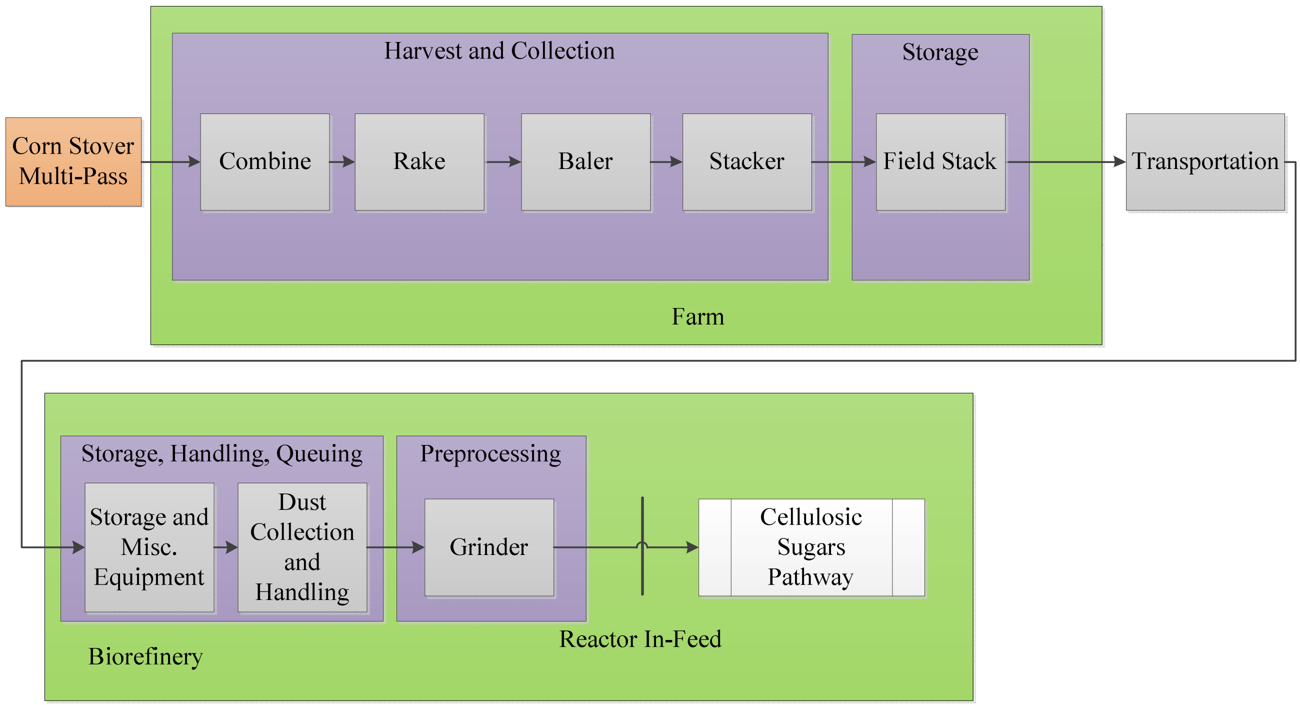

Figure 3. Detailed supply chain design for multi-pass harvest corn stover.

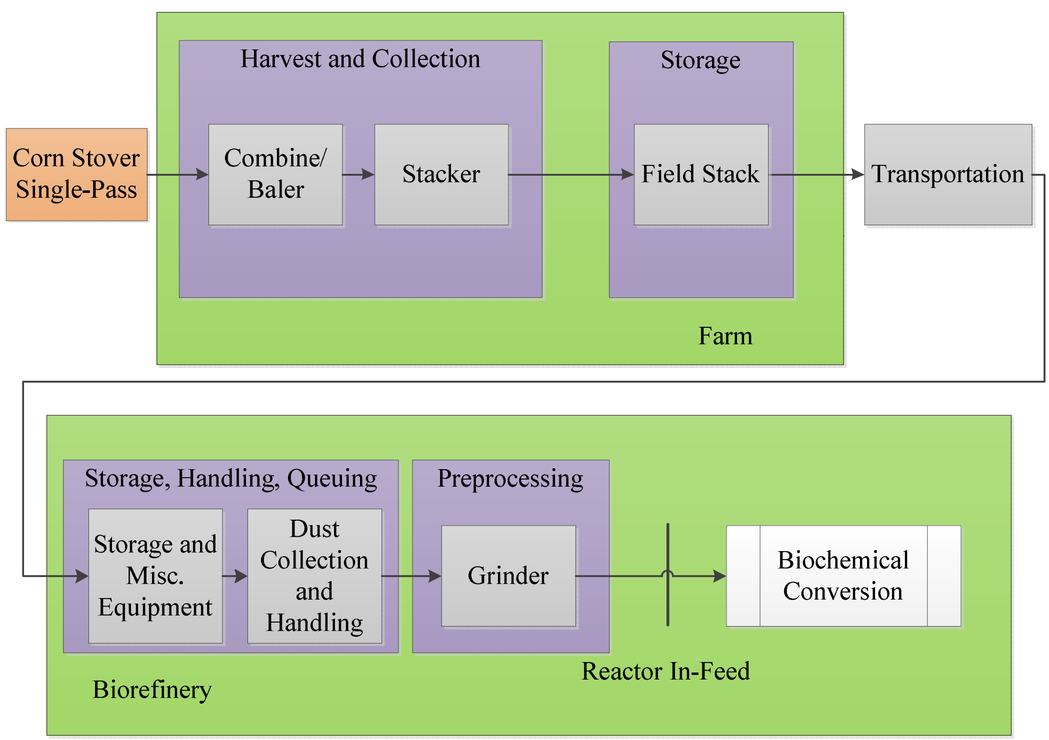

Figure 4. Detailed supply chain design for single-pass harvest corn stover.

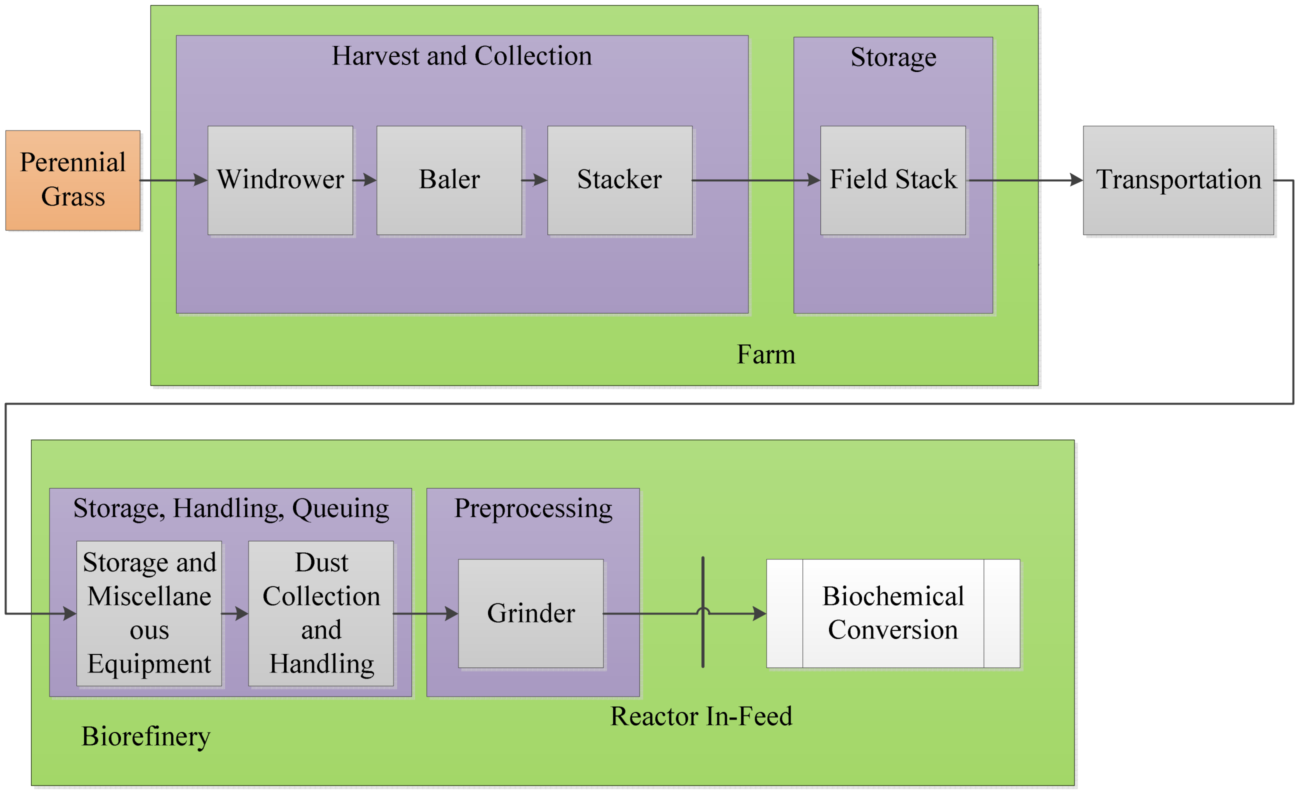

Figure 5. Detailed supply chain design for perennial grasses.

Bio-oil and Syngas Pathway Supply Chains

The feedstock supply chain designs for thermochemical biofuel conversion systems, specifically focused on fast pyrolysis, are typically focused on delivering clean wood chips to the reactor throat. This presents both cost and feedstock quality challenges in trying to achieve the $80/DMT target. Using the Least Cost Formulation Spatial Tool a high impact formulation based forest thinning, logging residues, and loblolly pine creates an opportunity to meet the feedstock cost and quality targets for bio-oil and syngas conversion pathways (Fig. 6).

Forest thinning and logging residues are low cost resources to procure, but also have unfavorable quality specs, specifically ash content. Because these resources are low cost supply chains that include active ash management preprocessing unit operations can be included. Specifically in this design a hot water extraction unit operation is used to reduce the ash content. The identified formulation uses 40% forest thinnings, 40% logging residues, and 20% purpose grown pine (Table 2). The forest thinning and logging residues are reduced to 2.25% and 2.25% ash respectively with the hot water extraction unit operation. The purpose grown pine is debarked and chipped at the landing resulting in an ash content of 0.5%. Forest thinnings and logging residues are delivered through supply chains that include the ash reduction unit operation at costs below the $80/DMT target, but the ash reduction technology has not yet been demonstrated to achieve levels below 2%. The 20% fraction of clean pine chips does not meet the cost target coming in at nearly $100/DMT, but provides low ash material to support meeting that conversion spec. The complete formulation meets both the cost and feedstock quality targets.

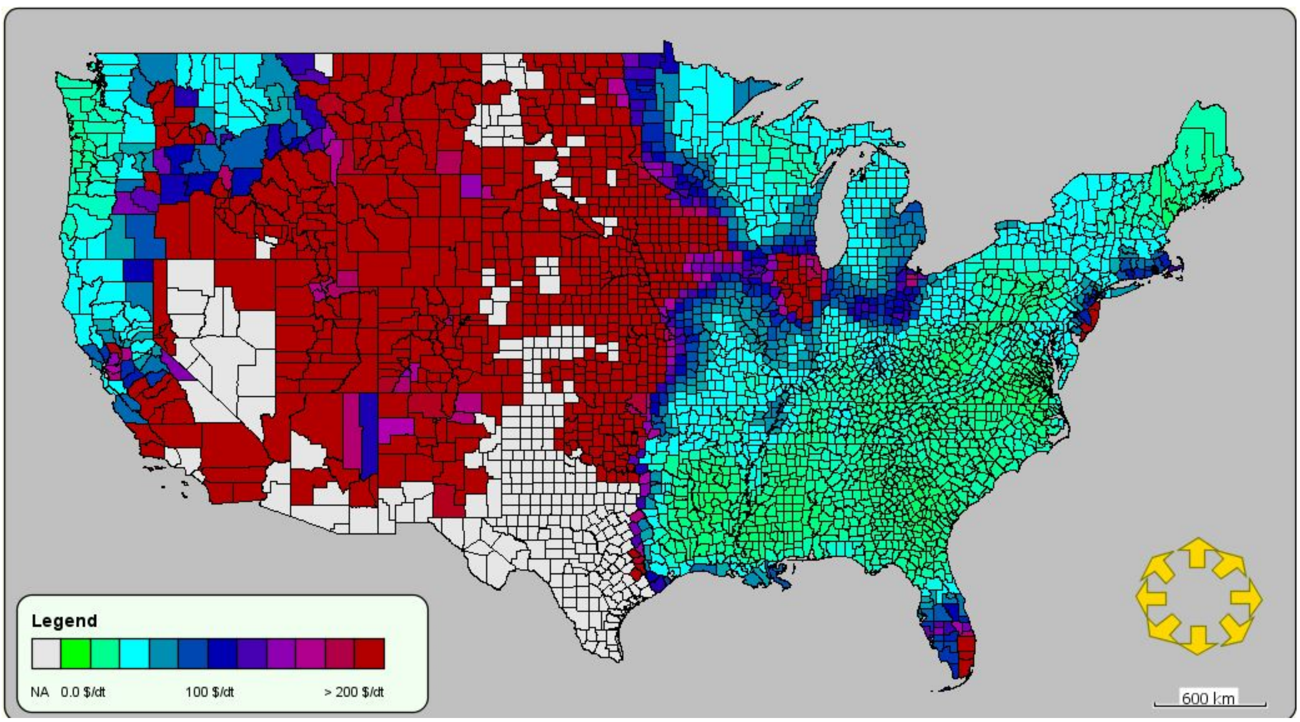

Figure 6. Farm gate/forest landing cost profile for forest thinning, logging residue, and loblolly pine blends in 2017.

Table 2: List of costs and specifications for woody feedstocks and blends for thermochemical conversion.

Feedstock	Reactor Throat Feedstock Cost ($/ton)	Formulation Fraction (%)	Reactor Throat Ash (%)	Reactor Throat Moisture (%)
Forest Thinnings	76.40	40	2.25	10.0
Logging Residues	74.13	40	2.25	10.0
6”-8” Purpose Grown Pine	98.52	20	0.5	10.0
Delivered Formulation Totals	**79.92**	**100**	**1.9**	**10.0**

The supply system design for the Southeast blends the three chosen feedstocks (thinnings, residues, and pulpwood) inside the “depot” which is located inside the biorefinery gate (Fig. 7). Initial harvest, collection, and preprocessing occurs at the landing while secondary preprocessing, storage, and handling occur within the gates of the biorefinery. For the thinnings and pulpwood feedstocks, harvest and collection involve a feller buncher and a skidder (Fig. 8 and 10). Residues do not include a harvest and collection operation (Fig. 9). At the landing all feedstock are chipped but only pulpwood includes a debarking process. For each feedstock, chips are transported to the “depot” at the biorefinery in a semi and chip trailer. Within the depot at the biorefinery, storage, and handling and queuing include an asphalt pad, loader, conveyors, truck scale, and electro-magnet. For pulpwood preprocessing involves a grinder and a waste heat dryer. For thinnings and residues, preprocessing includes a chip cleaning operation as well as a waste heat dryer and grinder.

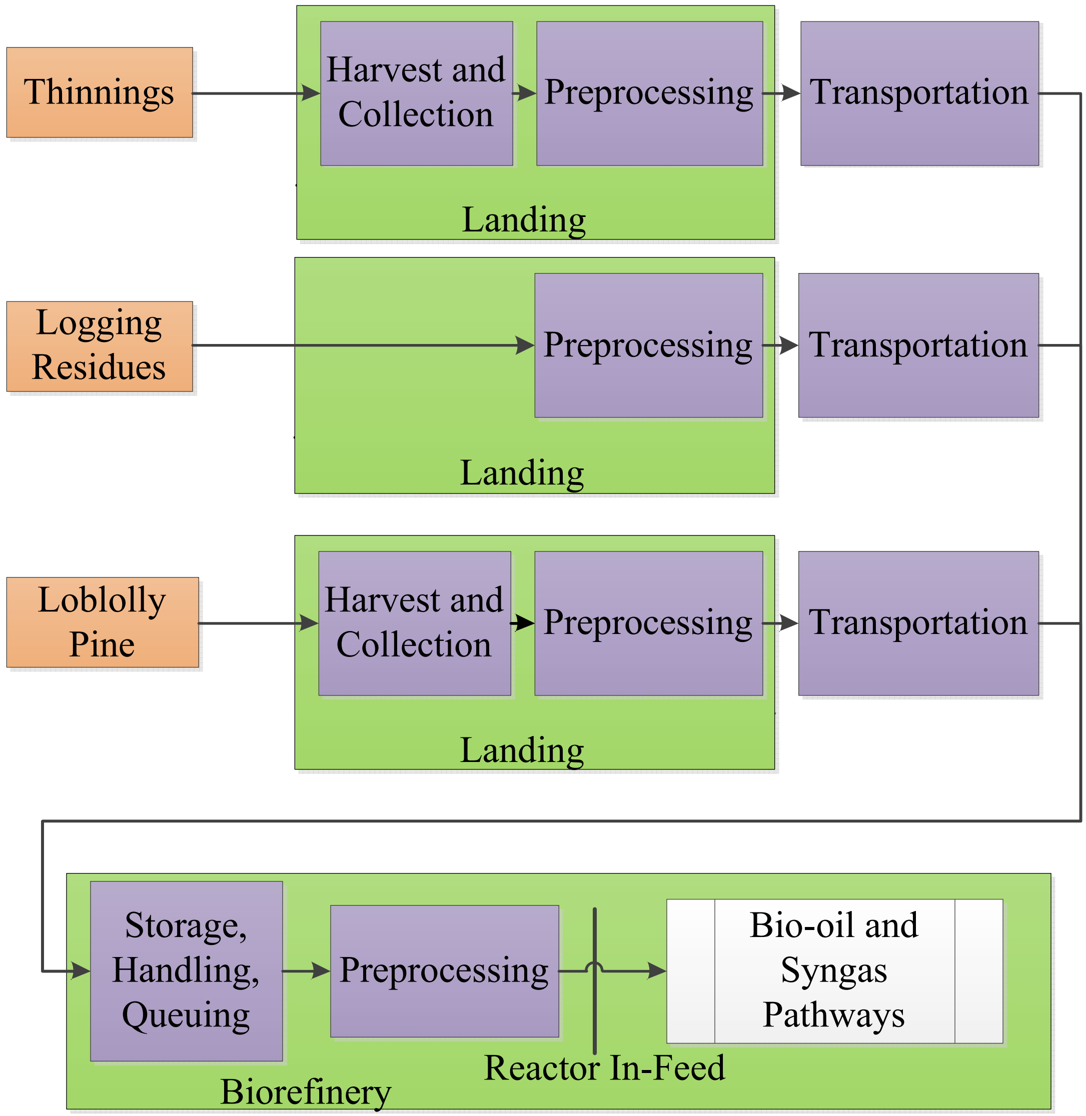

Figure 7. Supply chain design for formulated forest thinning, logging residues, and loblolly pine.

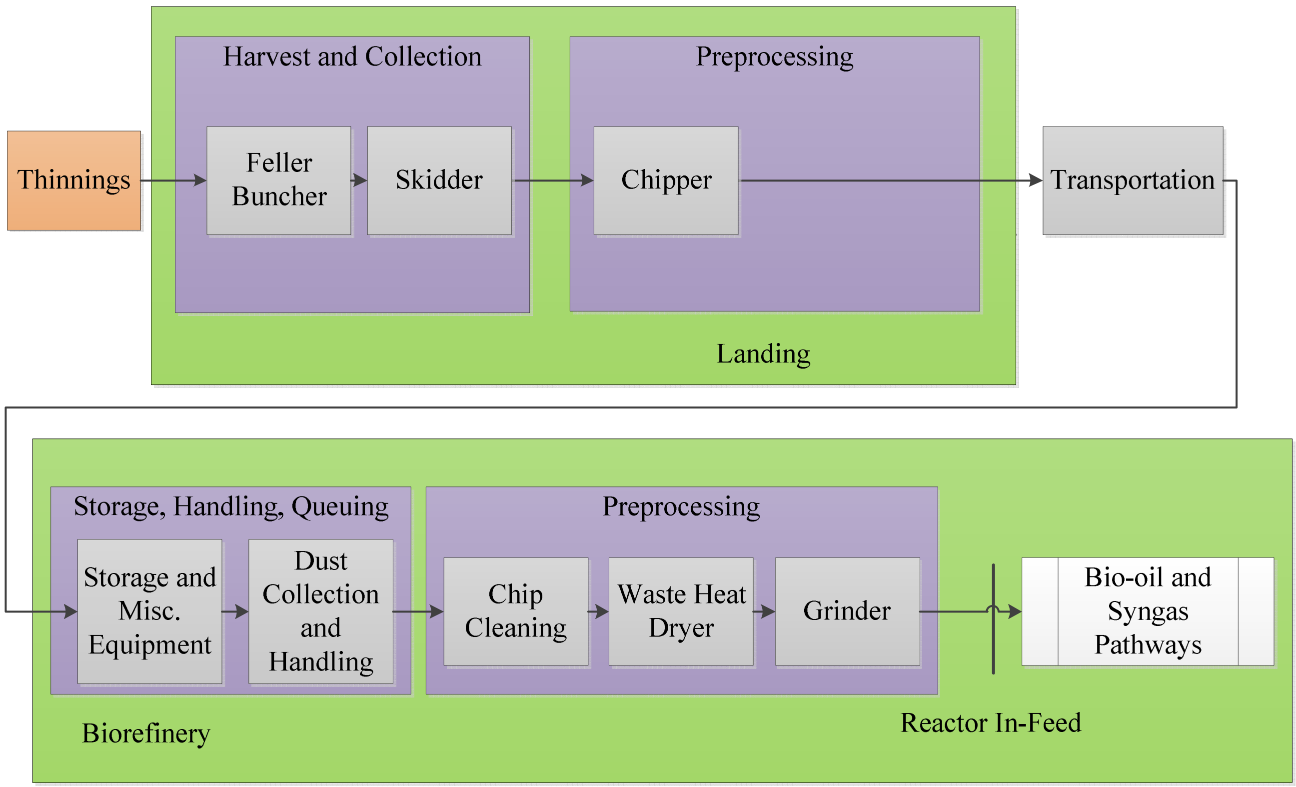

Figure 8. Detailed supply chain design for forest thinnings.

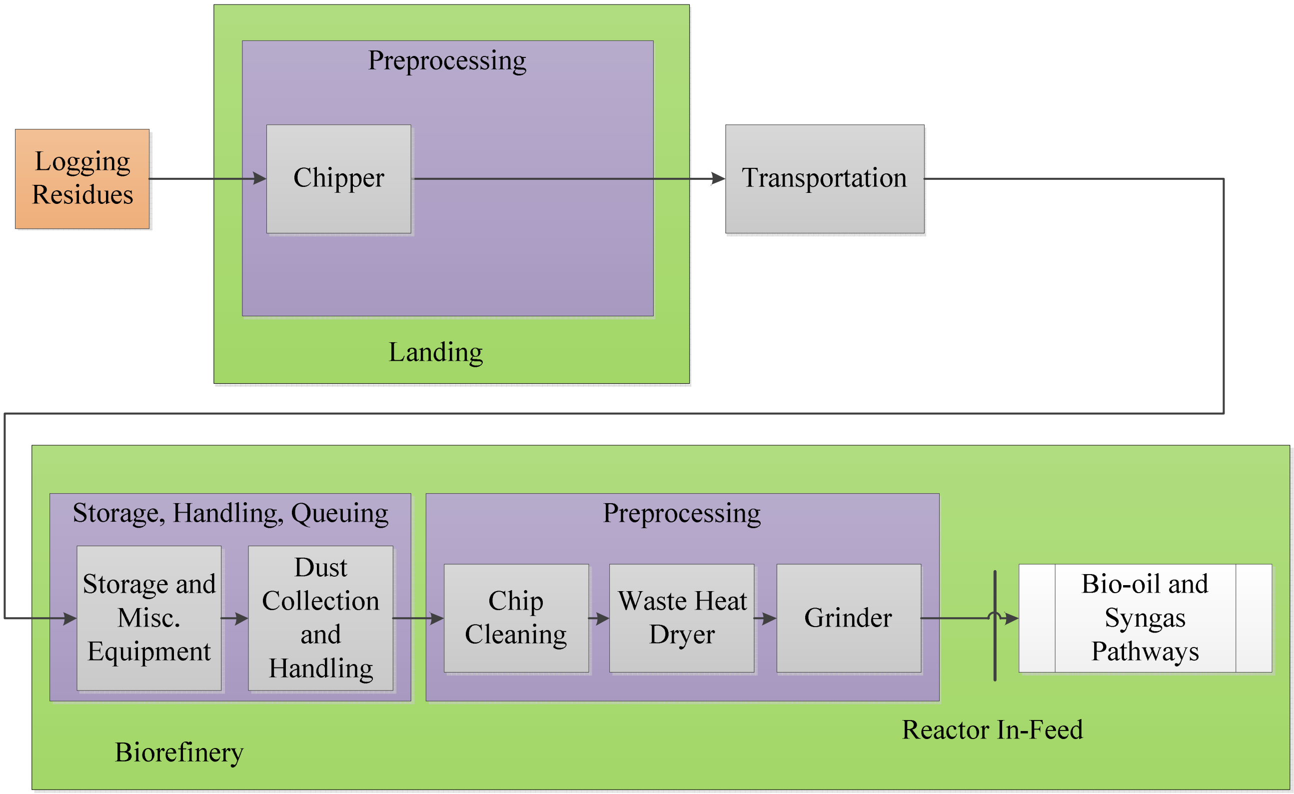

Figure 9. Detailed supply chain design for logging residues.

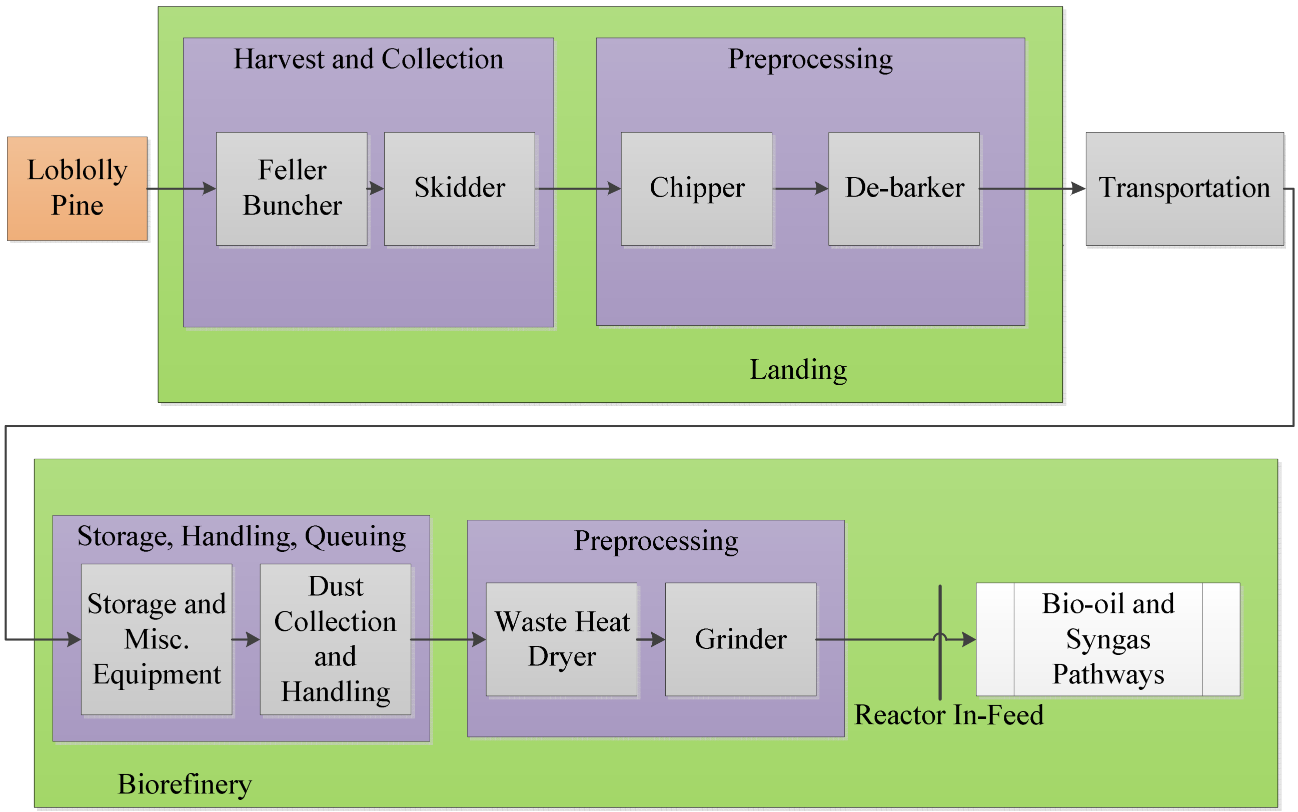

Figure 10. Detailed supply chain design for loblolly pine.

Conclusions:

Preliminary results on feedstock supply chains delivering material to cellulosic sugar, bio-oil, and syngas conversion pathways demonstrate that with the ability to blend multiple feedstocks and include some preprocessing operations it is possible to acquire much high volumes of material, reduce feedstock variability and meet the required $80/ton cost of material to the throat of the biorefinery. Much more research needs to be done both on the performance of blended material as well as the blending strategies themselves. In addition, the current pre-conversion systems are expensive and those costs could prove to be a significant challenge when trying to meet the future cost targets. However, there is on-going research at the INL as well as universities and industry to address these challenges.

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